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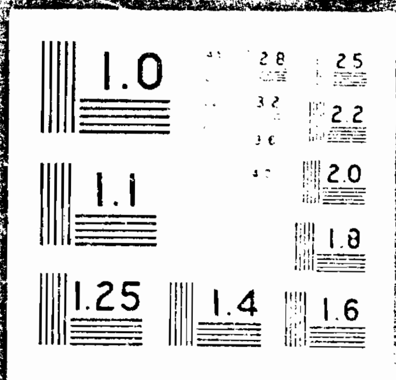

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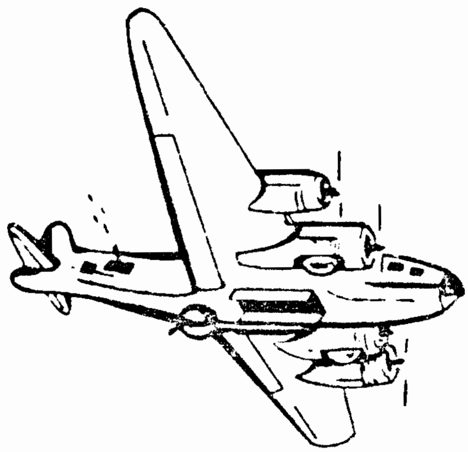
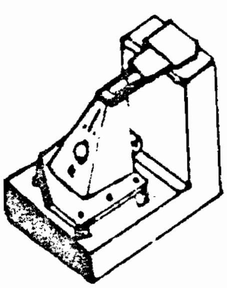


MEMORANDUM
REPORT No. 582

Description of the Eniac Converter Code



W. BARKLEY FRITZ

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

MEMORANDUM REPORT NO. 582

December 1951

DESCRIPTION OF THE ENIAC CONVERTER CODE

by

W. Barkley Fritz

Project No. TB3-0007 of the Research and
Development Division, Ordnance Corps

A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

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MEMORANDUM REPORT NO. 582

Fritz/rgd
Aberdeen Proving Ground, Md.
26 December 1951

DESCRIPTION OF THE ENIAC CONVERTER CODE

ABSTRACT

This report is intended as a working manual for personnel preparing problems for the ENIAC. It should also serve as a guide to those groups who have computing problems that could be solved on the ENIAC.

The report discusses the ENIAC from the point of view of the coder, describing its memory as well as the code itself. The 94 instructions which make up the Converter Code are discussed in complete detail describing what the instruction accomplishes as well as how to use each instruction. A few remarks are made on the more general subject of problem preparation for large scale computers in general based on the experience of operating the ENIAC.

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SECTION I INTRODUCTION

The ENIAC-the Electronic Numerical Integrator and Computer-was the first high speed, electronic, general purpose, digital computing machine. It was designed and constructed at the Moore School of Electrical Engineering of the University of Pennsylvania by Dr. John W. Mauchly, Mr. J. Presper Eckert, Jr., and their capable staff, for the Ballistic Research Laboratories at the Aberdeen Proving Ground, Maryland.

The ENIAC was completed in February 1946 in Philadelphia and moved to the Ballistic Research Laboratories in 1947 where it has been in continual operation since November of that year. It is operated 24 hours per day for a period beginning 0800 Monday through 2400 Friday.

At present the ENIAC is controlled by a code which incorporates a specially designed unit known as the Converter as a basic part of its operation; hence the name, "ENIAC Converter Code". These code digits are brought into the machine either through the Reader from standard IBM cards or from the Function Tables, two digits at a time. The Converter converts these digits to a sequence of operations such that the specified ENIAC instruction described in this report is carried out. The details of how the machine carries out these instructions are described in reference 4.

The ENIAC has an IBM Reader (type 797), as an input device, and a Punch (an IBM punch type 518), which serves as an output, punching on cards the numbers computed by the machine. Available for the processing of the cards are the following pieces of IBM equipment: 1) Key Punch (type 031), 2) Sorter (type 075), 3) Tabulator (type 416, 4) Reproducer (type 513), and 5) Interpreter (type 552).

The ENIAC has been made available to a large number of government agencies as well as private organizations with government contracts. Among these outside agencies have been the following: 1) The Atomic Energy Commission, 2) United Aircraft Corporation, 3) Cornell Aeronautical Laboratory, Inc., 4) University of California, and 5) The Institute for Advanced Study. Approval for the use of the machine must be obtained through the Department of the Army, Office of the Chief of Ordnance, Washington, D. C., ATTN: ORDTB Ballistic Section. Usually it is advisable to confer with the staff of Computing Laboratory, BRL, Aberdeen Proving Ground, Md., before submitting a request in order that an estimate can be made of the amount of machine time required to complete the problem. At present a transfer of funds is required at the rate of $35 per hour of machine time or $800 for a full 24 hour day. The coding of the problem will be performed by the ENIAC Branch. It is always advisable for the sponsor to bring a clearly written statement of the problem to Aberdeen when coming to discuss possible ENIAC solution. The Computing Laboratory has a number of other machines available for use by outside groups. Reference 3 gives an introduction to the capabilities of these other machines in comparison to the ENIAC.

SECTION II LISTING OF SYMBOLS

The following symbols are used in explaining the ENIAC Converter Code.

a,b,c,d,e,f....	single decimal digits (2 such letters placed side by side in alphabetical sequence such as ab represent a two digit number, etc.)
$\alpha, \beta, \gamma, \delta$, ...	represent 1, 2, 3, 4, or 6 digit numbers (used when single digit representation is not necessary)
A,B,C,D,E,F,G,H,J,K	the signed 10 digit numbers in the 10 fields of the Constant Transmitter
AB	the A (left) and B (right) sides of the function tables (control panels)
U,V,W,X,Y,Z	signed 10 digit numbers as normally stored in the accumulators
1,2,..., 20	designation of the 20 ENIAC accumulators frequently followed by parentheses to denote decades of the accumulator involved, such as 15 (3, 2, 1) to denote the three right-most places of accumulator 15. An 11 in the parenthesis is used to denote the PM.
6_1	6 (11, 10, 9)
6_2	6 (8, 7)
6_3	6 (6, 5, 4)
6_a	6 (3, 2, 1)
8_a	8 (3, 2, 1)
Acc	accumulator (high speed machine register)
AV or $\| \|$	absolute value
AT	add time (200 microseconds at 100 KC operation)
CT	conditional transfer
Cl	clear
D	delay
DS	drop sign
FT	function table

FTC	function table constant
FTN	function table number (frequently called numerics)
H	halt
L	listen (storage instruction)
M	minus
MP	master programmer
NaD	next "a" digits (a = 2, 4, 6)
P	plus
Pr	print (actually order to "punch" certain numbers in an IBM card)
Rd	read
SC	selective clear
La	shift left "a" places
Ra	shift right "a" places
T	talk (add instruction)

SECTION III DESCRIPTION OF THE ENIAC MEMORY

The ENIAC has essentially three types of memory: 1) fixed, 2) intermediate, and 3) electronic.

1) The fixed (switch set or plug wire controlled memory) consists of four function tables containing a total of 400 lines and 2 lines (or fields) of the constant transmitter designated JK. These lines are normally fixed throughout the operation of a problem, but can be changed between runs if necessary. The function table lines each contain 12 digits and 2 algebraic signs arranged so that each side (designated A or B) contains a signed 6 digit number. The JK switches of the constant transmitter consist of 2 lines of 10 digits each with attached signs.

Each of the four function tables contain 100 lines. Table I contains 4 lines of switch set memory and 96 lines controlled by 2 triple-panel and 4 single panel IBM plugboards. These 96 lines may be easily changed by simply inserting new plugboards. The remaining 3 tables contain ten position switches which are set manually. Each of the control panels may be disconnected from the machine and manually set without interferring with the operation of the ENIAC if the current program does not require the use of this function table.

These 400 fixed lines can be used to store either numerical information or code digits. When the line is used for code digits, coding must start at the beginning of the line. If the line is used to hold numerical information, the digits are placed so as to be brought into the electronic memory in the most convenient form.

The ENIAC addresses which are used to call out the indicated lines of programming are shown in the table below:

Figure I

F.T.	ENIAC Address	F.T. Line
I	1 ab	ab
II	2 ab	ab
III	3 ab	ab
IV	4 ab	ab

where $00 \leq ab \leq 99$

Addresses 000-007 are used to designate the eight fields of the IBM card in the constant transmitter. Instructions may be taken from the constant transmitter at any time by merely sending the proper address to 6a. When the last instruction of field H has been completed, the machine will automatically read the next card in the Reader and perform the first instruction in field A of the new card by changing the address in 6a to 000.

2) The intermediate or relay memory consists of eight of the contant transmitter groups designated A through H. Each group contains a signed 10 digit number. This portion of the memory is fed by IBM cards either prepared in advance using standard IBM equipment or produced by the ENIAC as a result of earlier computations. As soon as the values have been read into the constant transmitter from the IBM card, the quantities are available to the arithmetic units of the ENIAC in the same time as the numbers in the accumulators. The control of the ENIAC from the constant transmitter has already been discussed in the previous paragraph.

3) The electronic or internal memory consists of 200 decimal digits or 20 accumulators each capable of storing a signed 10 digit number. By careful coding it is possible to store two 5 digit numbers, or an eight digit number and a 2 digit address, or other similar combinations. Only registers 6_1, 6_2, 13, and 15 are true accumulators, accumulating sums on reception. All other so called accumulators have the property of clearing what they have in storage before receiving a new quantity.

With the present code, only the following 13 accumulators can be used without storage restrictions: 1, 2, 3, 4, 5, 9, 10, 14, 16, 17, 18, 19, 20. These serve as high speed storage registers.

The specialized uses of the remaining 7 accumulators are discussed briefly in the next paragraphs. Further clarification can be obtained by referring to the specific instructions described in Section VI of this report.

6 is the control center of the code's operation. It is used in 4 parts as follows:

6 (11, 10, 9) = 6_1 is used as a signed 2 digit accumulator.

6 (8, 7) = 6_2 is used as a 2 digit accumulator.

6 (6, 5, 4) = 6_3 is used to hold the new address to be used following the positive branch of a conditional transfer (discrimination).

6 (3, 2, 1) = 6_a holds the current address, i.e., the designation of the line of the function table or the field of the constant transmitter from which the code digits are being taken.

7 is used as the denominator in each division. Otherwise it may be used for unrestricted storage.

8 (11-4) may be used for storage, but the right 3 decades, 8_a = 8 (3, 2, 1), are used as the FTN and FTC addresses. This address automatically advances by 1 at the completion of each FTN or FTC instruction.

11 is seldom available for even temporary storage. It is used to hold the multiplier for multiplication, to receive the B side of the function table in FTN instructions, and to receive the left hand field of the constant transmitter on those instructions.

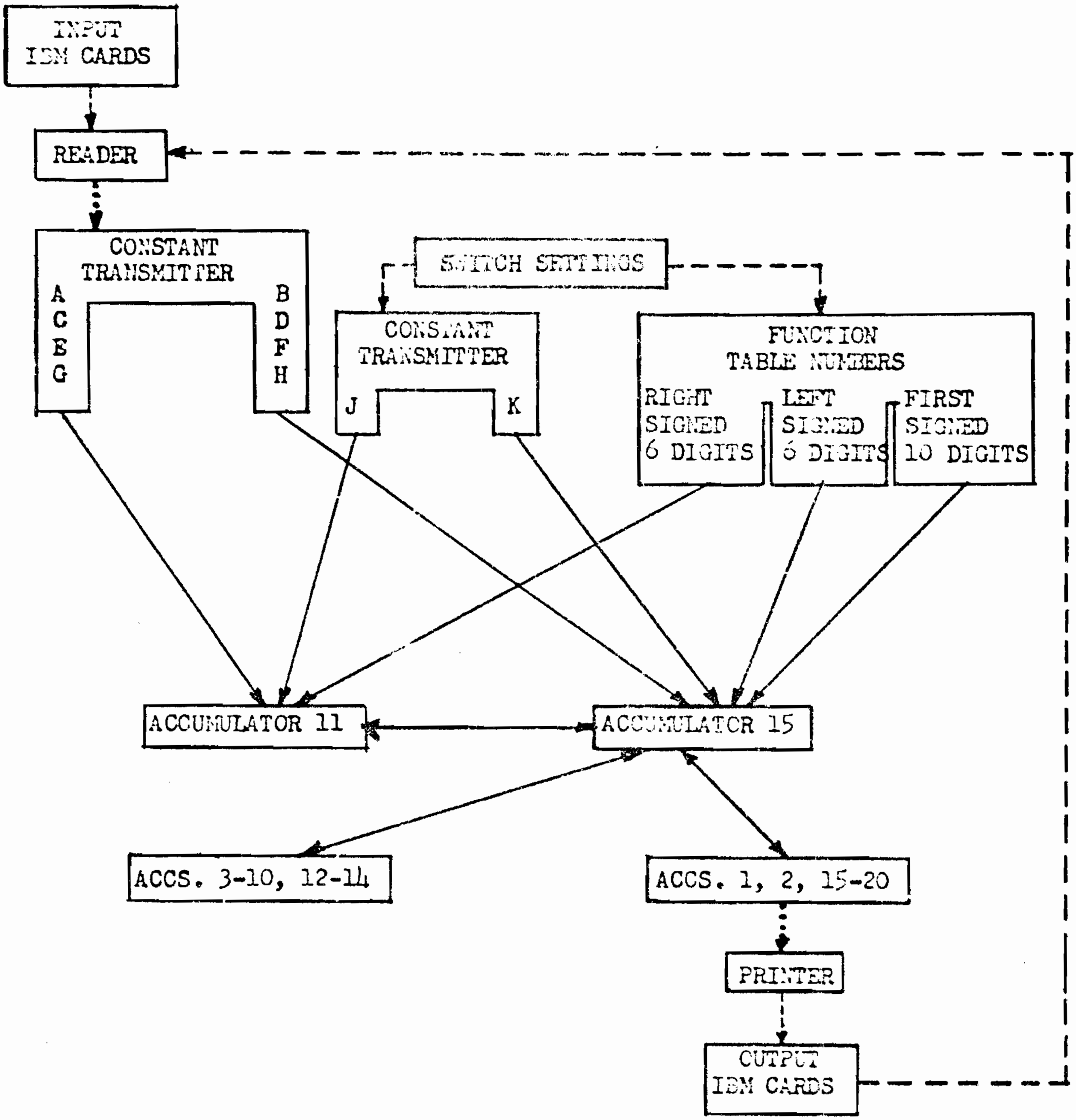
12 receives the multiplicand from 15 during multiplication and the remainder following a division or a square root. During shift primes, it receives the part of the number that is shifted off scale in 15. In each of these cases, it clears before reception.

13 adds into the product following a multiplication. It must be clear for many of the instructions and should not ordinarily be used for storage. The "bad" effects of not having 13 clear in the various instructions that "require" it to be clear may occasionally prove useful. An exact statement of what happens to the number in 13 during each of these special instructions is described in Section VI. In general, however, 13 should be clear for all instructions, except Rd, Constant Transmitter, FTN, FTC, Listens, Cl, SC, Pr, Talks, Delays, and Halts.

15 is the arithmetic center of the code's operation and cannot be considered as a storage accumulator.

Figure 2 summarizes the interrelation between the various ENIAC memory components.

Figure 2: Logical transfer of numbers among the component units of the ENIAC using the Converter Code



The solid line indicates automatic electronic operation on instruction, the dotted line indicates mechanical operation, and the dashed line manual operation.

SECTION IV. LISTING OF ENIAC INSTRUCTIONS

00 H p.33					50 AB p.15	60 L1 p.21	70 L3 p.21	80 L5 p.21	90 D p.33
01 1L p.17	11 11L p.17	21 1T p.23	31 11T p.23	41 M p.24	51 CD p.15	61	71 L2 p.21	81 L4 p.21	91 S.C. p.19
02 2L p.17	12 12L p.17	22 2T p.23	32 R1 p.21	42 R3 p.21	52 R5 p.21	62 12T p.23	72 N2D p.16	82 A.V. p.27	92 6_1 p.18
03 3L p.17	13 13L p.18	23 3T p.23	33 13T p.24	43 R2 p.21	53 R4 p.21	63 ÷ p.25	73 N4D p.16	83 $N3D6_a$ p.28	93 6_2 p.19
04 4L p.17	14 14L p.17	24 4T p.23	34 14T p.23	44 Rd p.14	54 EF p.15	64 $\sqrt{}$ p.26	74 N6D p.16	84 N6D6 p.28	94 i p.31
05 5L p.17	15 CL p.18	25 5T p.23	35 H p.33	45 Pr p.20	55 GH p.15	65	75 N3D8 p.32	85	95 di p.31
06 6L p.18	16 16L p.17	26 6T p.23	36 16T p.23	46 D.S. p.27	56 JK p.15	66 L'1 p.22	76 L'3 p.22	86 L'5 p.22	96 cdi p.32
07 7L p.17	17 17L p.17	27 7T p.23	37 17T p.23	47 FTN p.16	57 X p.24	67	77 L'2 p.22	87 L'4 p.22	97 FTC p.17
08 8L p.17	18 18L p.17	28 8T p.23	38 R'1 p.22	48 R'3 p.22	58 R'5 p.22	68 18T p.23	78 6R3 p.29	88	98
09 9L p.17	19 19L p.17	29 9T p.23	39 19T p.23	49 R'2 p.22	59 R'4 p.22	69 C.T. p.30	79 6_3 p.29	89 $N3D6_3$ p.30	99 D p.33
10 10L p.17	20 20L p.17	30 10T p.23	40 20T p.23						

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SECTION V. CLASSIFICATION OF ENIAC INSTRUCTIONS*

A. Storage Instructions

1 - Read (Rd)

2 - Constant Transmitter (AB, CD, EF, GH, JK)

3 - Next Digits (N2D, N4D, N6D)

4 - Function Table Number (FTN)

5 - Function Table Constant (FTC)

6 - α Listen (αL)

7 - 6 Listen (6L)

8 - 13 Listen (13L)

9 - 15 Clear (Cl)

10 - 6_1 Listen and Talk (6_1)

11 - 6_2 Listen and Talk (6_2)

12 - Selective Clear (SC)

13 - Print (Pr)

B. Shift and Shift Prime Instructions

1 - R (1-5), L (1-5)

2 - R' (1-5) or L (9-5), L' (1-5) or R (9-5)

C. Arithmetic Instructions

1 - Add or Talk (+ or αT)

2 - Minus (- or M)

3 - Multiply ($\times$)

4 - Divide ($\div$)

5 - Square Root ($\sqrt{}$)

6 - Absolute Value (AV)

7 - Drop Sign (DS)

*The same logical listing is followed in Section VI.

D. Control Instructions

1 - Next 3 digits to 6a (N3D6a)

2 - Next 6 digits to 6 (N6D6)

3 - Right 3 digits of 15 to 6a (6R3)

4 - Right 3 digits of 15 to 6_3 (6_3)

5 - Next 3 digits to 6_3 (N3D6_3)

6 - Conditional Transfer (CT)

7 - i Count Conditional Transfer (i)

8 - Direct Input to MP Stepper (di)

9 - Clear Direct Input to MP Stepper (cdi)

10 - FT Address (N3D8a)

11 - Delays (D)

12 - Halts (H)

SECTION VI. DESCRIPTION OF THE CONVERTER CODE*

A. Storage Instructions

These instructions are used to get numbers into the machine, to transfer numbers from one part to another, and to place numbers computed by the machine on IBM cards.

Instruction	Description	Acc.	Before	After	A.T.
		Contents of Affected Accs.			
Rd 4	1. Read				
	a) Takes the eight 10-digit signed numbers from the next standard 80 column IBM card in the Reader and places these numbers in the relays of the intermediate storage unit known as the Constant Transmitter.				1500

* The code is described as used during 1951. Certain minor modifications are contemplated, i.e. changing certain of the code digits and also reducing the number of AT required to complete nearly all of the instructions by shortening the basic sequence.

		Instruction Description	Contents of Affected Accs. Acc.	Before	After	A.T.
	b)	These input cards have either been prepared by the IBM key punch and reproducer gang punch or by the ENIAC itself. In the latter case they contain the results of previous ENIAC runs (possibly sorted) and are read back into the machine for further computation.				
	2.	<u>Constant Transmitter</u>				
AB 50	a)	Clears 11.	11	X	A	6
	b)	The number in the Constant Transmitter field designated	15	Y	Y + B	
CD 51		by the first letter of the code	11	X	C	6
		symbol goes to 11 and that number designated by the second	15	Y	Y + D	
EF 54		letter to 15 adding to any	11	X	E	6
		quantity already there.	15	Y	Y + F	
GH 55			11	X	G	6
			15	Y	Y + H	
	c)	The numbers in the Constant				
JK 56		Transmitter relays are changed	11	X	J	6
		only by the reading of a new card.	15	Y	Y + K	
	d)	Negative numbers are placed on IBM cards by placing x punches in the first and sixth columns of the field and listing the digits directly. However the ENIAC style number (10's complement) is set on JK. The PM switches are set to M (2 switches for J and 2 for K).				

Contents of Affected Accs.

Instruction		Description	Acc.	Before	After	A.T.
	3.	Next Digits				
N2D 72ab	a)	Sends next 2, 4, or 6 digits from the FT to 15.	15	X	X + ab	15
N4D 73abcd	b)	These digits add to 15 at the right hand side to 15 (2,1), 15 (4-1), and 15 (6-1) respectively.	15	X	X + abcd	21
N6D 74abcdef			15	X	X + abcdef	27
	c)	Occupies 2, 3, or 4 order positions respectively.	13	0	0	
	d)	13 must be clear. If 13 is not clear its number will be subtracted from the number in 18. (18-13→18)*				
	4.	Function Table Number				
FTN 47	a)	Clears 11.	11(11-5)	α	β	13
	b)	F.T. transmits 12 digits and 2	11(4-1)	θ	0	
		signs from the F.T. line speci-	15(11-5)	γ	γ + δ	
		fied by the address in 8a.	15(4-1)	ϕ	ϕ	
	c)	11(11-5) receives the sign and 6 digits (β) from the B side and 15(11-5) receives the sign and 6 digits (δ) from the A side of the F.T. If 15 already holds a number, δ is added to 15(11-5) and 15(4-1) is left unchanged.	8(3-1)	λ	λ + 1	
	d)	The address in 8a is automatically advanced by 1.				
	e)	The ENIAC number is placed on the F.T.; in other words, negative numbers are stored as M with the 10's complement. (see order on FT Address on page 32)				

* This is a peculiarity of the way in which the machine is programmed. Occasionally it may be useful. (Reference 4)

		Contents of Affected Accs.			
Instruction	Description	Acc.	Before	After	A.T.
	5. Function Table Constant				
FTC 97	a) Function table line designated in 8a sends the first signed 10 digits (Y) to 15 adding to any number already there.	15	X	X + Y	13
	b) The address in 8a is automatically advanced by 1.				
	c) Zeros may be set on the two right most digit switches of the F.T. line.				
	d) For negative numbers the 10's complement should be set and the left PM switch set to M. For example - 1234567890 is set as M 8765432110ab c. The last two digits and the PM may be set to anything without affecting the way the instruction is performed. Normally they are set to 00 P.				
	6. Acc. α Listen ($\alpha \neq 6, 13, 15$)				
1L 01 2L 02 3L 03 4L 04 5L 05 7L 07 8L 08 9L 09 10L 10 11L 11 12L 12 14L 14 16L 16 17L 17 18L 18 19L 19 20L 20	a) Clears α ($\alpha \neq 6, 13,$ or 15)	15	X	0	6
	b) α receives the number from 15.	α	Y	X	
	c) 15 clears after transmission.				
	d) 6L and 13L are described separately below, since somewhat special conditions apply in each case.				

Instruction	Description	Contents of Affected Accs.			
		Acc.	Before	After	A.T.
	7. <u>Acc. 6 Listen</u>				
6L 06	a) This instruction is the same as the α listen described above;	6	Y	X	9
	the right 3 digits of 15 become the new address.	15	X	0	
	b) The order following 6L will be the first order of the line now specified in 6a (formerly 15 (3,2,1))				
	c) This order thus serves 2 purposes: (1) places numbers in 6 (11-4) (2) serves as an unconditional transfer where the new address may be computed by the machine or brought in through the constant transmitter.				
	8. <u>Acc. 13 Listen</u>				
13L 13	a) 13 receives the number from 15	13	Y	X + Y	6
	without first clearing.	15	X	0	
	b) 15 clears after transmission.				
	9. <u>Acc. 15 clears</u>				
CL 15	a) Clears 15.	15	X	0	6
	b) To clear any Acc.: (1) clear 15. (2) Give the appropriate listen order.				
	10. <u>6_1 Listen and Talk</u>				
6_1 92	a) The number in 15 (11,2,1) adds to the number in 6_1 and the sum goes	6_1	α	$\alpha + \delta$	10
	to both 6_1 and 15 (11,2,1).	6(8-1)	β	β	
	b) To clear 6_1 without disturbing	15(11-3)	γ	0 $(\alpha+\delta \geq 0)$	
	the remainder of 6 we must use the following sequence of orders: CL, 6_1, M, 6_1. This sequence		γ	9's $(\alpha+\delta<0)$	
	also clears 15.	15(11,2,1)	δ	$\alpha + \delta$	

Instruction	Description	Acc.	Before	After	A.T.
		Contents of Affected Accs.			
	c) 13 must be clear. If it is not clear its number will add to the number in 1 $(1+13\rightarrow 1)$	13	0	0	
	d) The 6_1 and 6_2 instructions are combinations of the listens described in this section and the talk instructions described on page 23.				
6_2 93	11. <u>6_2 Listen and Talk</u>				
	a) The number in 15 (2,1) is added to the number in 6_2	6_1	α	α	10
	and the sum goes to both 6_2 and 15 (2,1).	6_2	β	$\beta + \delta$	
	b) This order may be used only when 2 digits are brought directly into 15(2,1). This 2 digit number is made minus before the order is used if we wish to subtract from a quantity already contained in 6_2. 6_2 can never be made to store a negative number.	6(6-1)	γ	γ	
		15(11-3)	P00000000	0	
			M99999999	0	
		15 (2-1)	δ	$\beta + \delta$	
		13	0	0	
	c) 13 must be clear. If it is not clear, its number will add to the number in 1 $(1+13\rightarrow 1)$				
	d) If any number exists in 15(4,3) it will be added to 6_1, since we have carry over between 6_2 and 6_1. Thus we may control two induction variables stored in 6_1 and 6_2 with this one instruction.				
	12. <u>Selective Clear</u>				
S.C 91	a) Clears all accumulators (α) except 6_a.	α	X	0	8

Instruction	Description	Acc.	Before	After	A.T.

Contents of Affected Accs.

Instruction Description — Acc. Before After A.T.

b) A manually controlled switch is available on each accumulator to prevent its clearing if desired for a particular problem.

13. Print

Instruction	Description	Acc.	Before	After	A.T.
Pr 45	a) Punches on the next IBM card in the Printer the contents of 1, 2, 15, 16, 17, 18, 19, 20.	1,2,15-20	X	X	1000-3000

b) If any of these Accs. contain numbers that are unimportant, it is not necessary to list these fields when tabulating or the print switches for that field may be turned off on the machine.

c) These accumulators do not clear when printing.

d) The print time varies depending on the rate of printing, taking 3000 AT on successive prints. The normal print followed by 2000 or more AT of computing requires about 1000 AT's. An interlock automatically controls the timing.

B. Shift and Shift Prime Instructions

These instructions are used: (a) to line up the numbers so that as many significant digits as required can be saved, (b) to keep decimal points set correctly for arithmetical operations, and (c) to separate 10 digit numbers into appropriate parts.

Shift instructions can be interpreted in at least two different ways. First the decimal point can be regarded as being fixed so that the accumulator contains a number less than 1, multiplied by an appropriate power of 10. In this case, the shift instructions can be interpreted as multiplying the number by a power of 10 according to Figure 3.

R1	10^{-1}	L'5	10^{-5}	L1	10^{1}	R'5	10^{5}
R2	10^{-2}	L'4	10^{-6}	L2	10^{2}	R'4	10^{6}
R3	10^{-3}	L'3	10^{-7}	L3	10^{3}	R'3	10^{7}
R4	10^{-4}	L'2	10^{-8}	L4	10^{4}	R'2	10^{8}
R5	10^{-5}	L'1	10^{-9}	L5	10^{5}	R'1	10^{9}

Figure 3.

Secondly, if the decimal point is not regarded as fixed, but having any position you wish to give it without using powers of 10 (except in the case where negative powers are necessary) the shift instruction may be regarded as a physical movement of the number to the right or left carrying the decimal point with it.

In the shifts the digits shifted out of 15 are lost. In the shift primes these digits are saved and are stored in 12.

Instruction			Description	Contents of Affected Accs. Acc.	Before	After	A.T.
		1.	Shifts				
R1	32	a)	Shifts the digits in 15 to	15	+abcdefghij	0abcdefghi	12
R2	43		the right or left the num-	15	"	00abcdefgh	
R3	42		ber of places indicated by	15	"	000abcdefg	
R4	53		the order symbol.	15	"	0000abcdef	
R5	52			15	"	00000abcde	
L1	60	b)	When negative numbers are	15	"	bcdefghij0	
L2	71		shifted n places to the	15	"	cdefghij00	
L3	70		right 9's appear in the	15	"	defghij000	
L4	81		left n places of 15.(See	15	"	efghij0000	
L5	80		also (g) under shift	15	"	fghij00000	
			primes). In all other				
			cases the decades vacated	13	0	0	
			by numbers as a result of				
			the shift are replaced by				
			zeros as indicated on the				
			right.				
		c)	Shifts do not affect the				
			sign.				

Instruction	Description	Contents of Affected Accs. Acc.	Before	After	A.T.
	d) 13 must be clear. If it is not clear its number will be subtracted from the number in 14. (14-13→14)				
	2. Shift Primes				
R'1(L9) 38	a) Shifts the number in 15	15	+abcdefghij	j000000000	12
	the number of places to	12	X	0abcdefghi	
R'2(L8) 49	the right or left as in-	15	+abcdefghij	ij00000000	
	dicated in the order	12	X	00abcdefgh	
R'3(L7) 48	symbol and places it in	15	+abcdefghij	hij0000000	
	12.	12	X	000abcdefg	
	b) Takes the original				
R'4(L6) 59	number in Acc. 15,	15	+abcdefghij	ghij000000	
	shifts it 10 minus the	12	X	0000abcdef	
R'5(L5) 58	number of places in-	15	+abcdefghij	fghij00000	
	dicated in the order	12	X	00000abcde	
	symbol in the opposite				
	direction and places it				
	in 15.				
L'1(R9) 66	c) The original number in	15	abcdefghij	000000000a	
	12 will be lost.	12	X	bcdefghij0	
L'2(R8) 77	d) We thus split our 10	15	abcdefghij	00000000ab	
	digit numbers in any	12	X	cdefghij00	
	manner we like.				
L'3(R7) 76	e) The sign of the number	15	abcdefghij	0000000abc	
	stored in 15 before this	12	X	defghij000	
	instruction is given is				
L'4(R6) 87	preserved with the num-	15	abcdefghij	000000abcd	
	bers that result from	12	X	efghij0000	
	this order in 12 and 15.				
L'5(R5) 86	f) The symbol in parenthe-	15	abcdefghij	00000abcde	
	sis indicates the shift	12	X	fghij00000	
	of 6 to 9 places that is				
	accomplished in 15.				

Instruction Description		Contents of Affected Accs.		
	Acc.	Before	After	A.T.
g) Note that M9...9 which is the complement representation of 0...01 is unchanged by a shift to the right; in other words, a right shift of a negative number introduces an error of +1 in the least significant place.	13	0	0	
h) 13 must be clear. If it is not clear its number will be subtracted from the number in 14 (14-13→14)				

Note: An L'0(61) instruction is available for saving the sign.

C. Arithmetic Instructions

These instructions are used to carry out the ordinary arithmetical operations. Often shift instructions are necessary to properly place decimal points and storage instructions to correctly position numbers.

Instruction		Description	Acc.	Before	After	A.T.
1T	21	1. Acc. α Talk (α ≠ 13)	α	X	X	6
2T	22	a) The number in Acc. α (α ≠ 13) is added to the number in 15 and the sum is held in 15.	15	Y	X + Y	6
3T	23					6
4T	24					6
5T	25					6
6T	26					8
7T	27					6
8T	28					7
9T	29					6
10T	30					6
11T	31					6
12T	62					6
14T	34					6
16T	36					6
17T	37					6
18T	68					6
19T	39					6
20T	40					6

				Contents of Affected Accs.			
Instruction			Description	Acc.	Before	After	A.T.
13T	33	2.	<u>Acc. 13 Talk</u>	13	X	0	6
		1)	The number in 13 is added to the number in 15 and the sum remains in 15.	15	Y	X + Y	
		2)	13 clears after transmission unlike the previous talk instructions.				

Note: See also 6_1 and 6_2 Listen and Talk on pages 18 and 19.

		3.	<u>Subtract or Minus</u>				
M	41	a)	Changes the sign and forms the	15	-X	+X	8
			10's complement of the number in	15	+X	-X	
			15 thus replacing the ENIAC	15	+0	+0	
			representation of the original number by the ENIAC representation of the negative.	13	0	0	
		b)	By using the talk and listen orders in combination with this minus order, subtraction can be carried out.				
		c)	This order does not affect the sign of +0.				
		d)	13 must be clear. If 13 is not clear it will add to the number in 1. (1+13→1)				
		4.	<u>Multiplication</u>				
X	57	a)	Before this order is used the multiplier must be placed in 11 and the multiplicand in 15. (11X15 + 13→15)	11	X	X	20
				12	Y	W	
		b)	The multiplicand goes from 15 to 12.				
		c)	Decimal points are additive; in other words, if the decimal point of the	13	Z	0	
			multiplier is m places from the left and that of the multiplicand n places from the left, then the decimal point of the product is m + n places from the left. m and n are frequently zero.	15	W	XW + Z	

	Instruction Description	Contents of Affected Accs.			
		Acc.	Before	After	A.T.
	d) 13 if not clear must contain a number where the decimal point is m + n places from the left.				
	e) All sign combinations are handled automatically.				
	f) When forming ac + bc, the form (a+b)c should be used to keep round-off error at a minimum.				
	g) Multiplication gives a rounded 10 place product by automatically adding a 5 to what would be the 11th place and giving carry over into the 10th place when the 11th place is greater than or equal to 5.				
	5. <u>Division:</u>				
÷ 63	a) Before this order is used the denominator must be placed in 7 and the numberator in 15.	7	X	X	About 120*
	b) The quotient 15/7 goes to 15.				
	c) If the decimal point of the numerator is n places from the left and that of the denominator d from the left, the decimal point of the quotient is n - d + 2 places from the left. n and d are frequently zero.	12 15 13	Y Z 0	Remainder Z/X 0	
	d) The four combinations of signs are handled automatically.				
	e) The design of the divider unit requires that there always be a zero in decade 10 of Acc. 7.				
	f) A basic requirement is that $\lvert Z\rvert<10^{n-d+2}\lvert X\rvert$ or if n=d (in particular n=d=o) then $\lvert Z\rvert < 100\lvert X\rvert$.				

* Depending on the size of the numbers involved.

Contents of Affected Accs.

Instruction Description

g) Division should be replaced by multiplication whenever possible since division is a much longer operation than multiplication.

h) 13 must be clear. If 13 is not clear its number will add to the number in 4. $(4+13 \rightarrow 4)$

i) When forming $\frac{ab}{c}$, the order of operations should be $(a/c) \cdot (b)$ to lessen round-off error.

6. <u>Square Root</u>

64 √ a) The number whose square root is to be extracted is placed in 15 prior to giving this order.

b) This number must be less than 2500000000.

Acc.	Before	After	A.T.
12	X	Remainder	About 120*
15	Y	$\sqrt{Y}$	
13	0	0	

c) If the decimal point of the radicand (Y) is at the far left, the decimal point of the square root is at the far left.

d) If the decimal point of the radicand is 2d places from the left, the decimal point of the root $(\sqrt{Y})$ is d places from the left.

e) Because of round off, the ENIAC gets 0000000010 as the square root of 0000000000.

f) If the number in 15 is negative through ENIAC error or inadequate programming, the machine will treat it as zero.

g) 13 must be clear. If 13 is not clear its number will add to the number in 7. $(7+13 \rightarrow 7)$

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*Depending on the size of the numbers involved.

Instruction Description				Contents of Affected Accs. Acc.	Before	After	A.T.
		7.	<u>Absolute Value</u>				
A.V.	82	a)	Takes the absolute value of the number in 15.	15	+X	X	9
		b)	13 must be clear. If the number is negative and 13 is not clear it will add to the number in 1 (1+13→1)	15 13	-X 0	X 0	11
		8.	<u>Drop Sign</u>				
D.S.	46	a)	Drops the sign of the number in 15.	15	+X	+X	7
		b)	Only the PM decade is affected. A positive number is left unchanged, but a negative number is replaced by the absolute value of the 10's complement.	15 13	-X 0	10^d -X 0	
		c)	This order is used (1) to insure the sign of a number, (2) for the storage of 2 numbers in one Acc.,* and (3) as a special device for computing $10^d - X$, where the decimal point of X is d places from the left. The sequence of orders to accomplish this is +X to 15, M, D.S. It is obvious that this sequence will not work if $X \leq 0$.				
		d)	13 must be clear. If 13 is not clear its number will add to the number in 11. (11+13→11)				

D. <u>Control Instructions</u>

The control instructions enable the coder to transfer the control of the ENIAC from one address to another either directly (unconditional transfer) or after investigating the sign of a number (conditional transfer). The Conditional Transfer gives the ENIAC its power for automatic operation, since most computations involve more or less simple inductions which in turn depend upon decisions based on the sign of a member. This instruction enables

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* More frequently, constants are added to numbers stored in partial accs. in order to ensure their being positive. The constant can be subtracted at the time the number is used.

the ENIAC to perform iterative processes, such as stepwise integrations and successive approximations. The i count C.T. provides a special type of conditional transfer to handle a fixed number of iterations.

Instruction		Description	Contents of Affected Accs. Acc.	Before	After	A.T.
	1.	<u>Next 3 digits to 6a</u>				
N3D6a 83	a)	Transfers control to the line of	6(11-4)	α	α	21
0a		coding specified in the second,	6a	def	abc	
bc		third and fourth digits following the 83.				
	b)	The first digit should be 0.	13	0	0	
	c)	6a is cleared and address abc is sent to 6a.				
	d)	In case this first digit is not zero, it is added into 6(4) and will alter the alternate address stored in 6_3.				
	e)	A N3D6a 0008 serves as an unconditional transfer to the first instruction on the next card in the Reader.				
	f)	13 must be clear. If 13 is not clear its number will be subtracted from 18. (18-13→18)				
	2.	<u>Next 6 digits to 6</u>				
N6D6 84	a)	6(6-1) is cleared and abcdef is sent to 6(6-1).	6(11-7)	α	α	27
ab	b)	Transfers control of the machine to the first instruction of the	6_3	β	abc	
cd		line specified by def.	6a	γ	def	
ef	c)	The + CT address abc is sent to 6_3.				
	d)	13 must be clear. If 13 is not clear its number will be subtracted from 18. (18-13→18)	13	0	0	

Instruction			Description	Contents of Affected Accs. Acc.	Before	After	A.T.
		3.	Right 3 digits of 15 to 6a				
6R3	78	a)	Clears 6a.	6(11-4)	α	α	13
		b)	15(3,2,1) transmits clear to 6a.				
		c)	Any other digits in 15(11-4) are lost in the process and 15 is clear at the completion of the order.	6a	β	δ	
				15(11-4)	γ	0	
		d)	6R3 is used as an unconditional transfer when the address is computed or read from the card. In each case the address is brought into 15(3-1).	15(3-1)	δ	0	
				13	0	0	
		e)	Serves as a special case of 6L which does not destroy 6_1,6_2, or 6_3.				
		f)	13 must be clear. If 13 is not clear it is subtracted from 10 (10-13→10).				

Note: M3D6a, M6D6, and 6R3 comprise the unconditional transfer instructions and must each be the final order of the line that is used since control of the machine is immediately transferred to another line. 6L is primarily a storage instruction but also serves as an unconditional transfer. (page 18)

Instruction			Description	Contents of Affected Accs. Acc.	Before	After	A.T.
		4.	Right 3 digits of 15 to 6_3				
6_3	79	a)	Clears 6_3.	6(11-7)	α	α	13
		b)	15(3,2,1) transmits clear to 6_3.	6_3	β	γ	
		c)	Any other digits in 15(11-4) are lost and 15 is clear at the completion of the instruction.	6a	δ	δ	*
				15(11-4)	θ	0	
		d)	13 must be clear. If 13 is not clear, its number will be subtracted from 20. (20-13→20)	15(3-1)	γ	0	
				13	0	0	

*Unless the instruction has carried over to the next line of coding in which case the address will have increased by 1.

				Contents of Affected Accs.			
Instruction Description				Acc.	Before	After	A.T.
		5.	Next 3 digits to 6_3				
N3D6_3	89	a)	Clears 6_3.	6(11-7)	α	α	26
	ab	b)	Sends the next 3 digits from the F.T. to 6_3.	6_3	β	abc	
	c0	c)	6_3 and N3D6_3 are both useful instructions for properly placing	6a	γ	γ	*
			the +CT address in 6_3.	13	0	0	
		d)	13 must be clear. If 13 is not clear, its number will be subtracted from 20. (20-13→20)				
		6.	Conditional Transfer				
C.T.	69	a)	Examines the sign of the number	15	X	0	
			in 15.	6(11-7)	α	α	
		b)	If the sign is minus continues	6_3	β	β	7
			with the next instruction.	6a	γ	γ	
		c)	If the sign is plus (zero is plus) transfers 6_3 to 6a and continues	6_3	β	0	14
			with the first instruction of the line now specified by 6a.	6a	γ	β	
		d)	15 is cleared.	13	0	0	
		e)	This order is frequently used in conjunction with the remote variable connection in which a sequence is required a number of times at various points during a problem. The address to which we want to return is placed in 6_3 before entering the sequence. A C.T. on a cleared 15 at the end of the sequence will return control to the required address. These remote variable connection addresses may be stored in other memory positions of the ENIAC, brought into 15 and then transferred to 6a by means of a 6R3.				

*Unless the instruction has carried over to the next line of coding in which case the address will have increased by 1.

Contents of Affected Accs.

Instruction Description

f) 13 must be clear. If 13 is not clear, its number will be subtracted from 10 (10-13→10) on the positive branch.

7. <u>i Count Conditional Transfer</u>

i 94 a) This instruction enables the coder to perform in succession a series of not more than three distinct iterative processes where the induction variable counts are preset on the switches of the Master Programmer unit (reference 1).

Acc.	Before	After	A.T.
15	X	0	
13	0	0	
6(11-7)	α	α	
6_3	β	β	7
6_a	γ	γ	
6_3	β	0	14
6_a	γ	β	

b) i serves essentially as a C.T. returning control to the first order of the sequence each time until the count is reached.

c) When the count is reached control continues with the next order.

d) The address of the first line of the sequence must be placed in 6_3 during the sequence.

e) After we complete one count we are prepared to do the next count in cyclic order.

f) 13 must be clear. If 13 is not clear, its number will be subtracted from 10 (10-13→10) on the positive branch, i.e. each time before the count is reached.

8. <u>Direct Input to MP Stepper</u>

di 95 a) If on occasion it is desired to skip one of the pre-set counts, the "di" instruction is given.

Acc.	Before	After	A.T.
			6

Instruction			Description	Contents of Affected Accs. Acc.	Before	After	A.T.
		b)	For example, suppose our preset induction counts are 5,10, and 15. After completing the first count we are automatically set to do the second when the next i is given. If however, we now give a di order, we will then skip the 10 count and prepare the machine to handle the 15 count.				
		9.	<u>Clear Direct Input to MP Stepper</u>				
cdi	96	a)	The cdi instruction returns the count to the first count set on the MP.				6
		b)	The cdi is useful when we are only using the one count, or when we wish to be certain the first count is set on the M.P. control.				

NOTE: Instructions 7, 8, and 9 have proven particularly useful in testing procedures on the ENIAC as well as for fixed induction variables. Instructions 8 and 9 are at present not used on the machine, but may be easily added when required.

Instruction			Description	Contents of Affected Accs. Acc.	Before	After	A.T.
		10.	<u>FT Address</u>				
N3D8	75	a)	Clears 8a.	8(11-4)	α	α+a	21
	ab	b)	a,b,c, and d are added to 8(4,3,2,1).	8a	β	bcd	
	cd	c)	This instruction is used to introduce a new FT address to 8.	13	0	0	
		d)	a is usually 0.				
		e)	In the case where this address is computed within the problem or brought into the machine through the constant transmitter an 8L order may be used, care being taken to preserve 8(11-4) if necessary.				

		Instruction Description	Contents of Affected Accs.			
			Acc.	Before	After	A.T.
		f) This instruction is required to set the initial address for the FTN or FTC instruction.				
		g) 13 must be clear. If 13 is not clear, its number will be subtracted from 18. (18-13→18).				
		11. <u>Delays</u>				
D	90	a) Does nothing but go to next instruction.				6
	99	b) Used following a C.T., when first order desired must be at the beginning of a new line.				
		12. <u>Halts</u>				
H	00	a) Halts the machine.				
	35	b) Useful in testing the problem on the machine or in coding checks on size of numbers.				
		c) A read order will servce as a halt when there are no more cards in the reader.				
		d) Any 2 digit number not used for a particular instruction will stop the machine.				

SECTION VII. PREPARATION OF PROBLEMS FOR THE ENIAC

The preparation of problems for a large scale digital computer has been thoroughly discussed in references 2, 3, and 7; however, in order to survey the procedures required in the preparation of a problem for the ENIAC, the following required steps can be stated:

1. The physical problem must first of all be reduced to a form suitable for machine computation; i.e., it must be expressed in the form of equations that can be handled numerically such as algebraic, ordinary differential, partial differential, or integral equations. In other words the problem must be stated in precise mathematical form.

2. A numerical procedure is then adopted which preferably is known or can be shown to converge to the desired solution. Depending on the type of problem, this may or may not be difficult.

3. The number size of all quantities to be handled by the machine is then determined. By introducing various scaling factors the numbers to be considered are frequently reduced to the open interval -1 to +1.

4. A logical description of the problem is then outlined by setting up a flow diagram of the machine's method of operation for the particular problem. The flow diagram represents a complete description of the ENIAC'S method for obtaining the solution to the problem.

5. The next step involves the substitution of the machine language for the numberical operations to be performed. When this step has been completed the coding has been essentially completed, however, in order to insure efficient machine usage, steps 6, 7, 8, and 9 are also required.

6. A sample problem or run of the problem is then completed using a desk computing machine to carry out the high speed machine method. When practical, this so-called test run should be devised so as to employ all of the coding. The results of this run are then compared with a direct solution of the problem obtained by solving the original equations by an independent method. Good check values are useful for a variety of cases, particularly those involving extreme conditions.

7. The coding is then checked by all personnel to be connected with operating the machine on the problem. Experience with a large number of problems during the past 3 1/2 years of the code's use has indicated the type of errors most likely to be made. In general the coding is checked to determine that the machine instruction is intended exactly as described in this manual.

8. The input data, including the input cards and the machine setup sheets, are then prepared.

9. At the time the problem was first accepted for ENIAC solution a rough estimate was made of the amount of machine time required to complete the desired solutions. Now however a more exact estimate can be made by applying the figures for the number of AT per instruction given in Section VI of this report. Applying this figure we determine the number of AT in each operation box. The number of times each box is used in each run is multiplied by the number of AT for that box to determine the number of AT per run. To obtain the number of minutes of actual operation multiply this figure by $(1/3) \times 10^{-5}$ times the number of cases or runs to be completed. In case the number of times a particular box is used is not known exactly, the range of times can be determined and an average obtained.

The figure so obtained will need to be modified to obtain a realistic time estimate because it is based on an assumption of perfect continuous operation at 100KC. A figure about twice that obtained by an exact consideration of AT seems to be about the best estimate of how long the problem will take to be solved on the machine. (See Reference 8).

A large number of problems have been completed on the ENIAC using the currently used Converter Code (or earlier, somewhat less efficient forms of this code). This report will not attempt to give a description of even a single program of machine instructions, however it should be pointed out than an ever improving catalogue of sequences are available for reference in adapting new problems to the ENIAC. For instance, the various trigonometric and exponential functions can be incorporated into new programs with very little difficulty.

Examples of many different types of problems involving interpolation, integration, finite differences, Monte Carlo, data reductions, etc. are available for reference as an aid in preparing new problems. Each new problem, however, presents new difficulties. Careful and thorough preparation of each problem seems to be the only answer to continuing successful machine operation.

SECTION VIII. REFERENCES

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2. Planning and Coding Problems for an Electronic Computing Instrument - Goldstine and von Newmann - Part II, Vol. 1,2,3.

3. Preparation of Problems for the BRL Calculating Machines - BRL Technical Note No. 104 - September 1949.

4. Detailed Program - ENIAC Converter Code (available for local distribution).

5. A Logical Coding System Applied to the ENIAC - R. F. Clippinger - BRL Report No. 673 (description of a theoretical 60 order code similar to the present code).

6. Description and Use of the ENIAC Converter Code - BRL Technical Note No. 141 (an early version of the present report by the same author describing the code as it was used in November 1949).

7. Notes of R. F. Clippinger and B. Dimsdale prepared for Ballistic Institute Coding Course.

8. An Operating Survey of the ENIAC - W. Barkley Fritz

W. Barkley Fritz

W. Barkley Fritz

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